FORECASTING RESEARCH DIVISION

Technical Report No. 61

Validation of Model Water Vapour using TOVS Satellite Sounding Data

by

R Renshaw

September 1993

Validation of Model Water Vapour using TOVS Satellite Sounding Data

A Paper presented at the 18th General Assembly of the European Geophysical Society, Wiesbaden

FORECASTING RESEARCH DIVISION

TECHNICAL REPORT NO. 61

R Renshaw

September 1993

Forecasting Research Division
Meteorological Office
London Road
Bracknell
RG12 2SZ

This document has not yet been published. Permission to quote from it must be obtained from an Assistant Director of the above Division.

Validation of model water vapour using TOVS satellite sounding data

ABSTRACT

The accurate representation of water vapour is of increasing importance in GCM's. Observations are needed to evaluate the models. Radiosondes can be used, but are limited in their usefulness. Radiosonde observations of water vapour can contain serious errors, are spot values, and the coverage of many parts of the globe is poor. Data from satellite sounding instruments, though not without fault, are free of some of these difficulties. The TOVS (TIROS–N Operational Vertical Sounder) instrument on the NOAA polar–orbitting satellites provides global coverage at a resolution comparable to that of modern GCM's. Observed radiances can be processed to provide information on water vapour as well as temperature. In this paper, TOVS data are used to evaluate water vapour from a global model. Some mention is given of planned future satellite sounding instruments, and of their potential benefit to the validation of GCM results.

1 Introduction

The TOVS (TIROS–N Operational Vertical Sounder) instrument (*ref* Smith et al, 1979) is carried on the NOAA satellites (National Oceanic and Atmospheric Administration) – at present, NOAA–11 and NOAA–12. NESDIS (National Environmental Satellite Data Information Service, Washington) receive observations from the satellites, process them, and pass them on, at reduced resolution, over the GTS (Global Telecommunications System). The satellite observations are expressed as equivalent black body brightness temperatures at the frequencies observed by the TOVS instruments. At the UKMO, we receive these data and process them to obtain temperature and water vapour profiles at each observation location. The processing involves taking a NWP model background profile (actually a six–hour model forecast from the UKMO Unified Model, global, *ref* Cullen 1990) of T and RH, and using a radiative transfer model to simulate the brightness temperatures as would be observed by TOVS. We then compare the observed and simulated brightness temperatures and proceed iteratively to get a profile that combines model background and satellite observations in a statistically optimal way (*ref* Renshaw 1992). As a part of

that work, we monitor differences between the satellite observations (of brightness temperature) and those simulated from the model background. Some of those differences are examined in this paper.

2 The Satellite Data

TOVS comprises three instruments, only one of which, HIRS, is considered here. HIRS (High–resolution Infra–Red Sounder) has twenty channels, one of which is in the visible, and the rest in the infra–red. The HIRS footprint is approximately 40km in diameter at the earths surface. We receive up to 80,000 observations per day from the two–satellite system. NESDIS classify individual observations as to whether NESDIS consider them to be contaminated by cloud or not. In this paper only NESDIS clear fields of view are used. Figure 1 shows a typical days coverage of clear and cloudy spots, from both satellites.

3 What HIRS is Measuring

Figure 2 is a set of weighting functions for the TOVS instruments. The weighting function for a channel is an indication of the relative contribution to the measurement for that channel of temperature at each level in the atmosphere. It is dependent upon the opacity of the atmosphere at the frequency being observed. Most HIRS channels are at frequencies where the strongest absorbers are gases reasonably well–mixed in the atmosphere, such as CO_2. For these channels, the opacity does not change greatly, and the positions of the weighting functions are fairly well fixed. For channels looking at frequencies where water vapour is radiatively active, the opacity is dependent upon the water vapour in the atmosphere. The more water vapour, the more opaque the atmosphere, the higher peaks the weighting function, and so, generally, the colder the measured brightness temperature. Thus HIRS measures water vapour indirectly, by measuring temperature.

HIRS has four channels significantly affected by water vapour – channels 8, 10, 11 & 12. HIRS 8 & 10 are primarily window channels. HIRS–11 peaks, nominally, near 700hPa, and HIRS–12 near 500–hPa.

4 Comparison of Satellite and Model Brightness Temperatures

4.1 ...by chart

Figure 3 is a contour chart of HIRS–12, satellite – model, for one day. The differences at each observation point have been averaged onto $10^o \times 10^o$ latitude / longitude boxes for ease of viewing. By far the biggest differences occur between 30^o North and 30^o South. The differences tend to be positive over the Tropics, and negative over the Poles. The dipole at 45^o South, 110^o West, in the South–East Pacific, colocates with a strong depression. The large values at approximately 50^o East over Antarctica may well be due to model problems in this area. If we take the satellite observations, and the forward model, to be accurate to within a few degrees, then the range of values on the chart (10.3 to -3.7) can be ascribed to model error. The positive differences over the Tropics could be due to the model being either too cold or too moist.

Figure 4 is a chart for HIRS–11 on the same day, and shows similar features to HIRS–12, although with smaller values. Figure 5 is the same chart for HIRS–10. It can be seen that most of the signal here occurs over regions with extreme skin temperatures or orography – the Sahara, New Mexico, Greenland, the Himalayas and the Poles. Figure 6 shows HIRS–5. HIRS–12 and HIRS–5 have similar weighting functions, but HIRS–5 is not strongly affected by water vapour. The differences for HIRS–5 are an order of magnitude smaller than those for HIRS–12, and do not show the same Tropics–Poles pattern. Table 1 shows the sensitivity of each channel to temperature for different layers of the atmosphere. HIRS–12 is nowhere an order of magnitude more sensitive than HIRS–5.

We conclude that figure 3 is showing the model to be too moist over the Tropics, and possibly too dry over the Poles. This is in accord with a known problem of the model – an over–active Hadley circulation. It may be being driven by an excess of moisture, and so latent heat, in the model over the Tropics. Alternatively, the excess moisture may be a symptom of the problem.

4.2 ...by time–series

Figure 7 is a time series of globally–averaged satellite minus model brightness temperatures for NOAA–11, channels 5, 10, 11 and 12. On the 9th March, a change was made to the diffusion of humidity in the model. (Horizontal diffusion of specific humidity was changed from D2 to D4.) It can be seen that there was a significant impact on the mean differences for HIRS–11 & 12. The impact on HIRS–5 was small (– beware the different vertical scales). This change is confirmed by verification against radiosondes. Figure 8 shows mean and root–mean–square differences, model minus sonde. The excess moisture in the model has been reduced. This agrees with the change in satellite minus model brightness temperatures in the time series.

5 Future Instruments

The TOVS package is due to be replaced by ATOVS – Advanced TOVS – in mid–1996. ATOVS will retain HIRS, and will replace the current microwave instrument MSU (Microwave Sounding Unit) by AMSU – Advanced MSU – comprising AMSU–A and AMSU–B. AMSU–B will have five water vapour channels. Their weighting functions, for a typical tropical atmosphere, are shown in figure 9.

There are plans to fly more complex instruments towads the end of the century. These will be either spectrometers or interferometers, and may have several thousand channels. Figure 10 compares the TOVS moisture channels with just a selection of the moisture channels planned for HIS – High spectral resolution Interferometer Sounder (*ref* Smith 1991). It is estimated that these will allow the measurement of water vapour with 10% accuracy and 1km vertical resolution.

6 Conclusions

Satellite sounding instruments can play a useful complimentary rôle to radiosondes in the observation of water vapour. Radiosondes provide spot values. Sounding instruments give information at a horizontal resolution comparable to that of current operational forecast models. Radiosondes have limited global coverage and there are problems regarding

accuracy and standardisation. Satellite data provide good coverage, from one instrument.

Vertical resolution is poor for present sounding instruments. It is difficult to quantify differences in brightness temperature from the model as errors in , eg, model specific humidity. Despite these difficulties, satellite sounding data can be used profitably to evaluate model water vapour. Sounding imagery and large–area statistics are useful tools in this. Future potential is promising.

References

Cullen, MJP 1990: *Introduction to the unified/forecast climate model*, Unified Model Documentation Paper No 1, Short–Range Forecasting Div'n, UK Met Office

Renshaw, RJ 1992: *The use of satellite sounding data in atmospheric data analysis*, MSc dissertation, Univ of Reading

Smith, WL 1991: *Atmospheric soundings from satellites – false expectation or the key to improved weather prediction ?*, Q.J.R.Met. Soc., **117**, 267–298

Smith, WL, HM Woolf, CM Hayden, DQ Wark and LM McMillin 1979:
The TIROS-N Operational Vertical Sounder, GARP Topic no 58, 1177–1187 Bull. Am. Meteorol. Soc.

$$\frac{d\,(\text{Brightness Temperature})}{d\,(\text{Level Temperature})} \qquad \frac{(\text{Kelvin})}{(\text{Kelvin})}$$

as calculated from three representative profiles,

using forward model RTTOV, NOAA-11.

		polar				mid-latitude				tropical			
	HIRS channel:	5	10	11	12	5	10	11	12	5	10	11	12
T	10mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	15mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	20mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	25mb	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
T	30mb	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00
T	50mb	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00
T	70mb	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T	100mb	0.02	0.00	0.00	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.01
T	150mb	0.03	0.00	0.01	0.01	0.02	0.00	0.01	0.02	0.01	0.00	0.01	0.02
T	200mb	0.03	0.00	0.01	0.02	0.02	0.00	0.01	0.03	0.01	0.00	0.01	0.04
T	250mb	0.02	0.00	0.01	0.03	0.01	0.00	0.02	0.05	0.02	0.00	0.02	0.07
T	300mb	0.02	0.00	0.01	0.04	0.02	0.00	0.02	0.09	0.03	0.00	0.02	0.11
T	400mb	0.03	0.00	0.02	0.08	0.03	0.00	0.04	0.14	0.04	0.00	0.04	0.12
T	500mb	0.03	0.00	0.06	0.13	0.04	0.01	0.09	0.11	0.05	0.02	0.10	0.08
T	700mb	0.04	0.02	0.09	0.04	0.04	0.03	0.08	0.01	0.04	0.05	0.07	0.00
T	850mb	0.03	0.03	0.08	0.01	0.03	0.06	0.06	0.00	0.03	0.09	0.03	0.00
T	950mb	0.01	0.02	0.03	0.00	0.01	0.04	0.01	0.00	0.01	0.06	0.00	0.00
T	1000mb	0.01	0.02	0.02	0.00	0.01	0.03	0.01	0.00	0.01	0.05	0.00	0.00
T	skin	0.08	0.77	0.12	0.00	0.04	0.60	0.02	0.00	0.01	0.39	0.00	0.00

TABLE 1.

FIG. 1

ONE DAYS COVERAGE OF TOVS FROM NOAA-11 & 12
VIA NESDIS

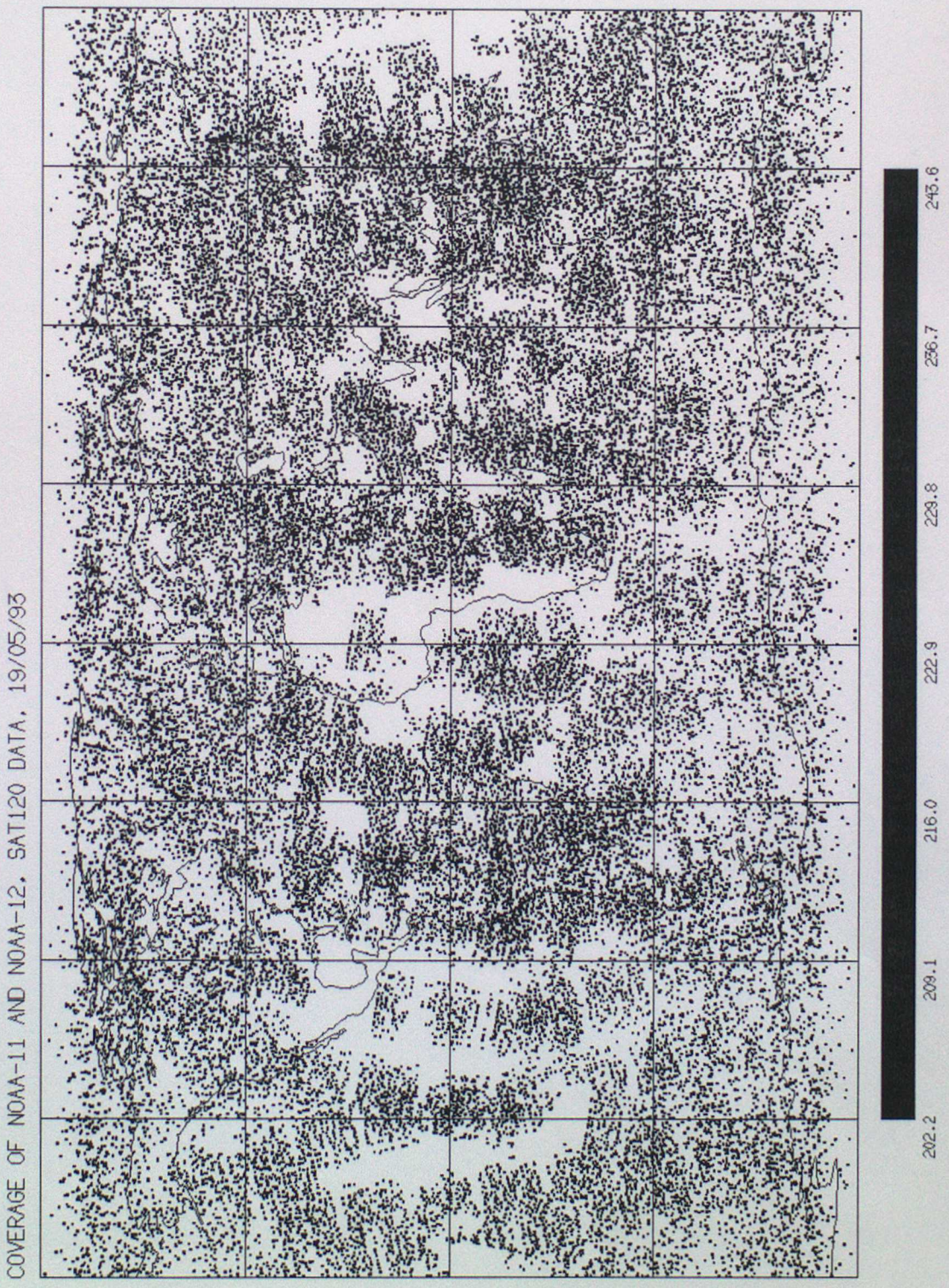
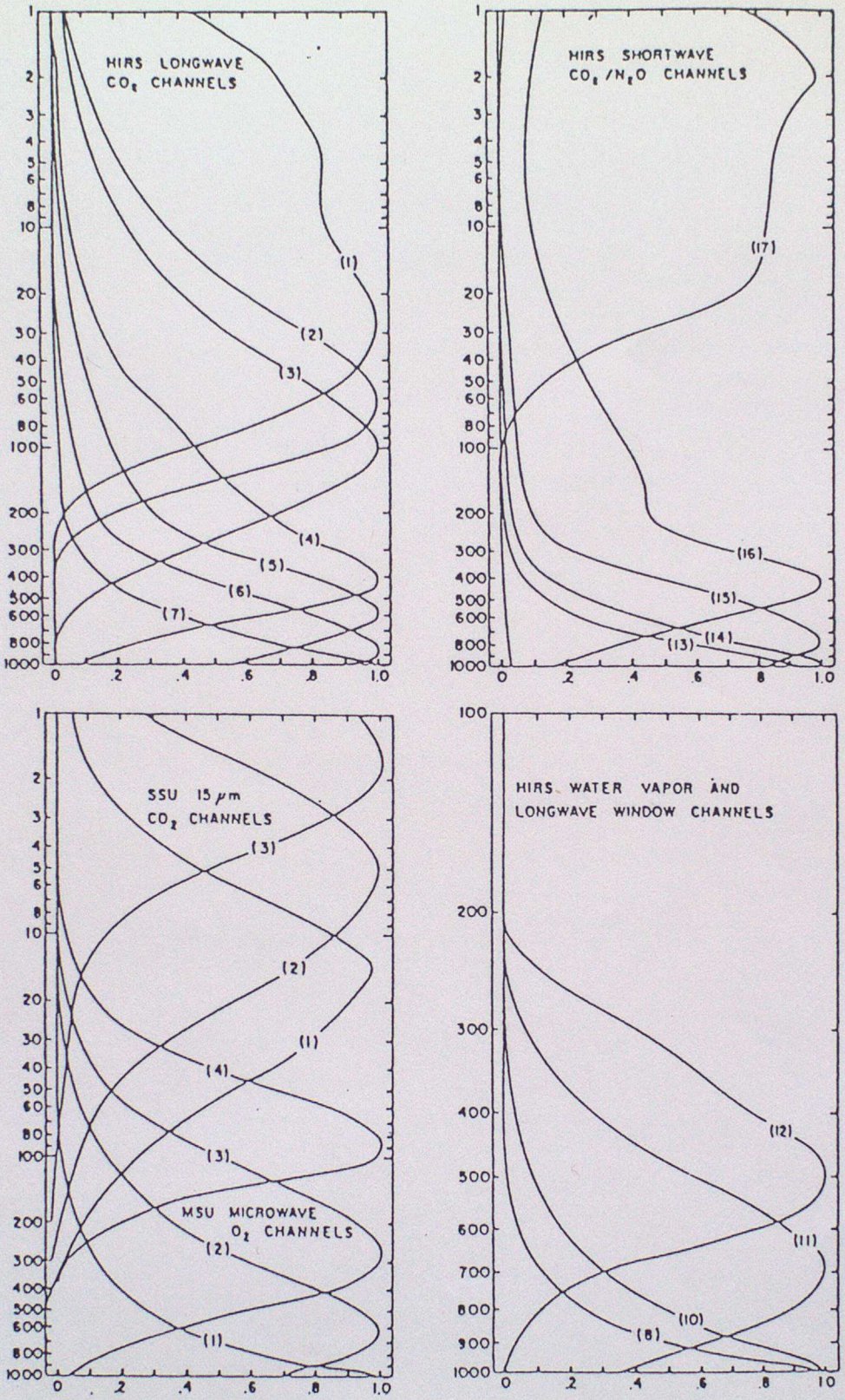


FIG. 2



TOVS weighting functions (normalized).

TAKEN FROM SMITH ET AL (1979)

FIG. 3

HIRS-12

OBSERVATIONS - MODEL

(BRIGHTNESS TEMPS IN KELVIN)

10° x 10° lat/lon boxes

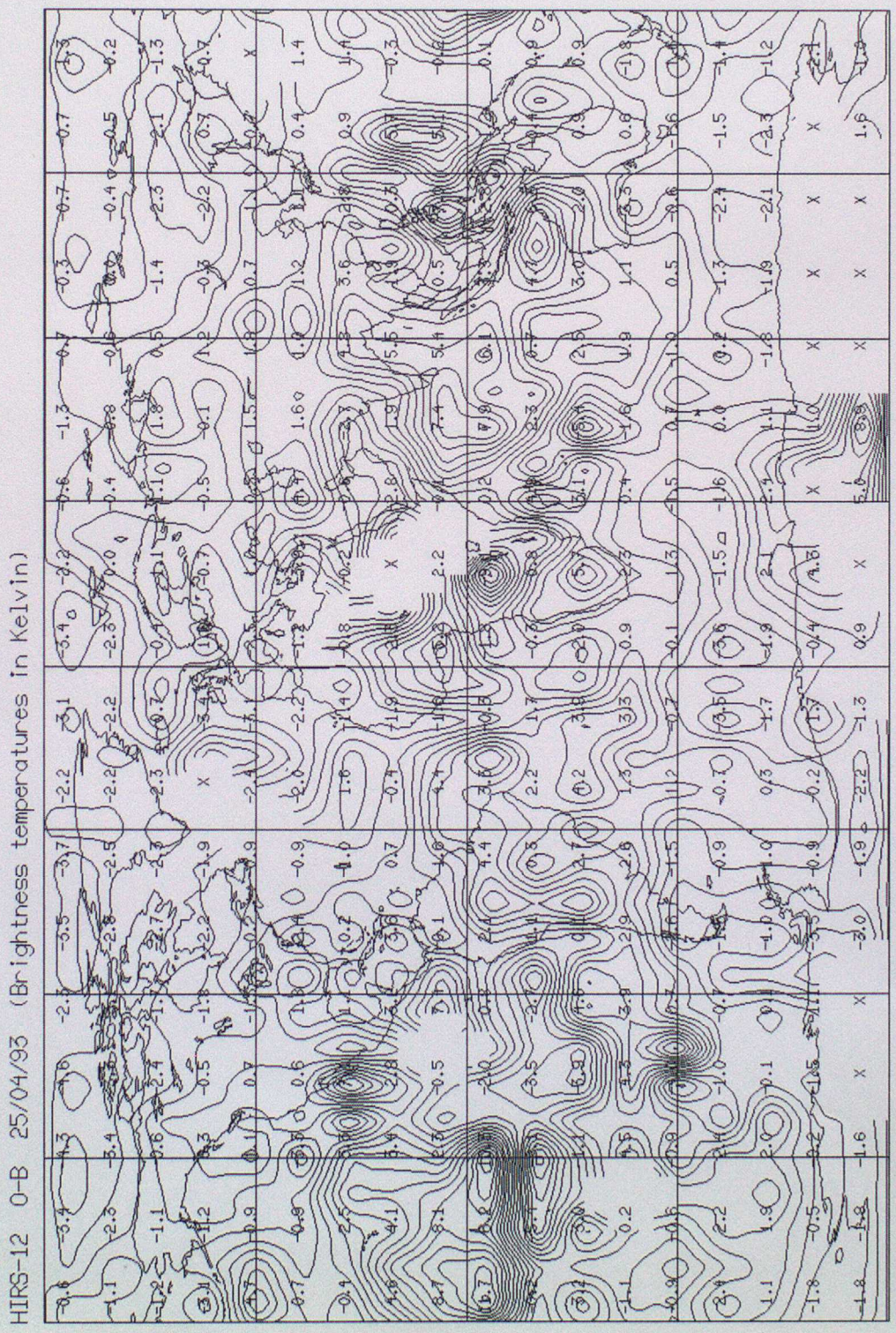


FIG. 4

HIRS - 11

OBSERVATIONS - MODEL

(BRIGHTNESS TEMPS IN KELVIN)

10° x 10° lat/lon boxes

FIG. 5

HIRS - 10

OBSERVATIONS - MODEL

(BRIGHTNESS TEMPS in KELVIN)

10° × 10° lat/lon boxes

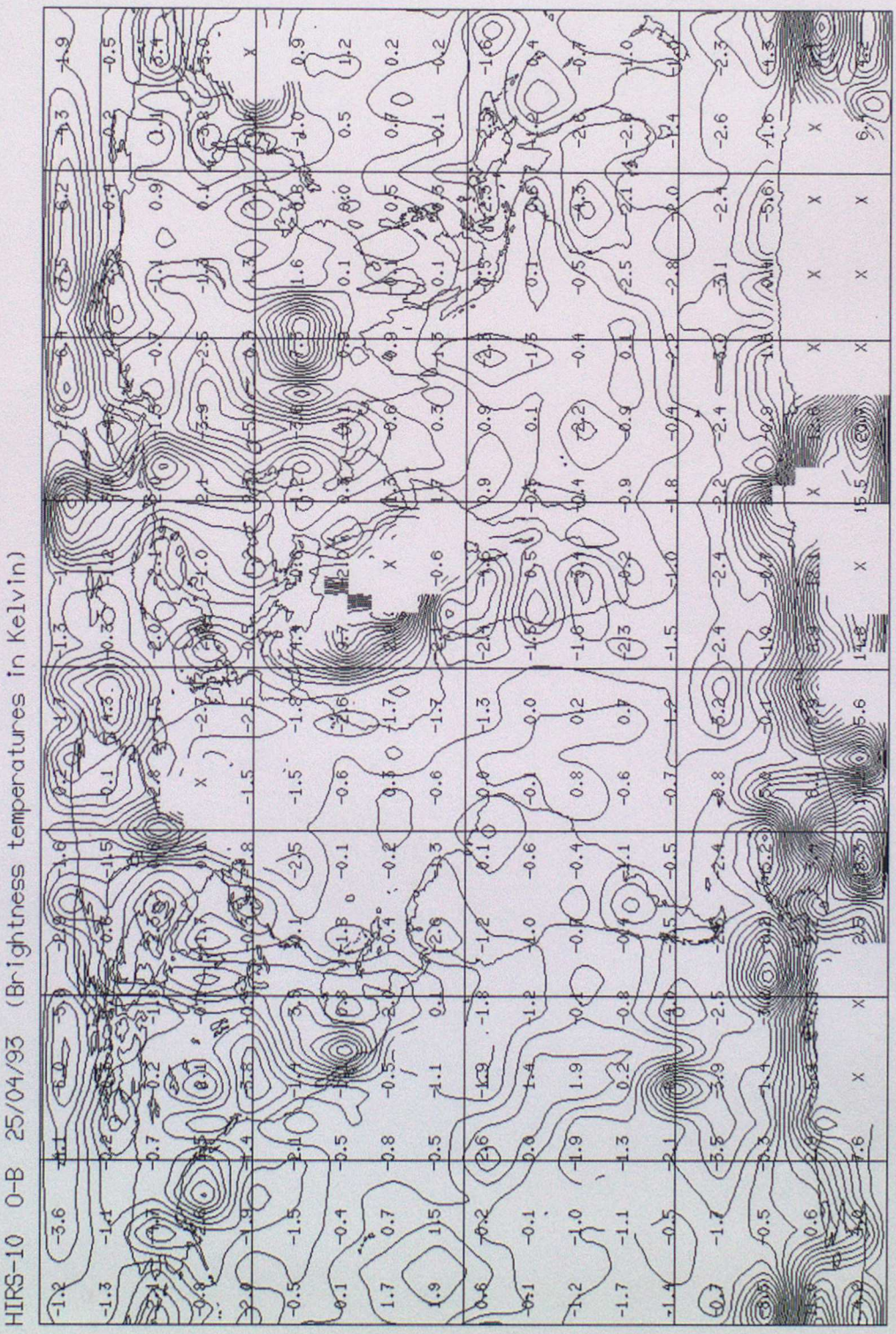


FIG. 6

HIRS-5

OBSERVATION – MODEL (BRIGHTNESS TEMPS, KELVIN)

25/04/93

10° × 10° lat/lon boxes

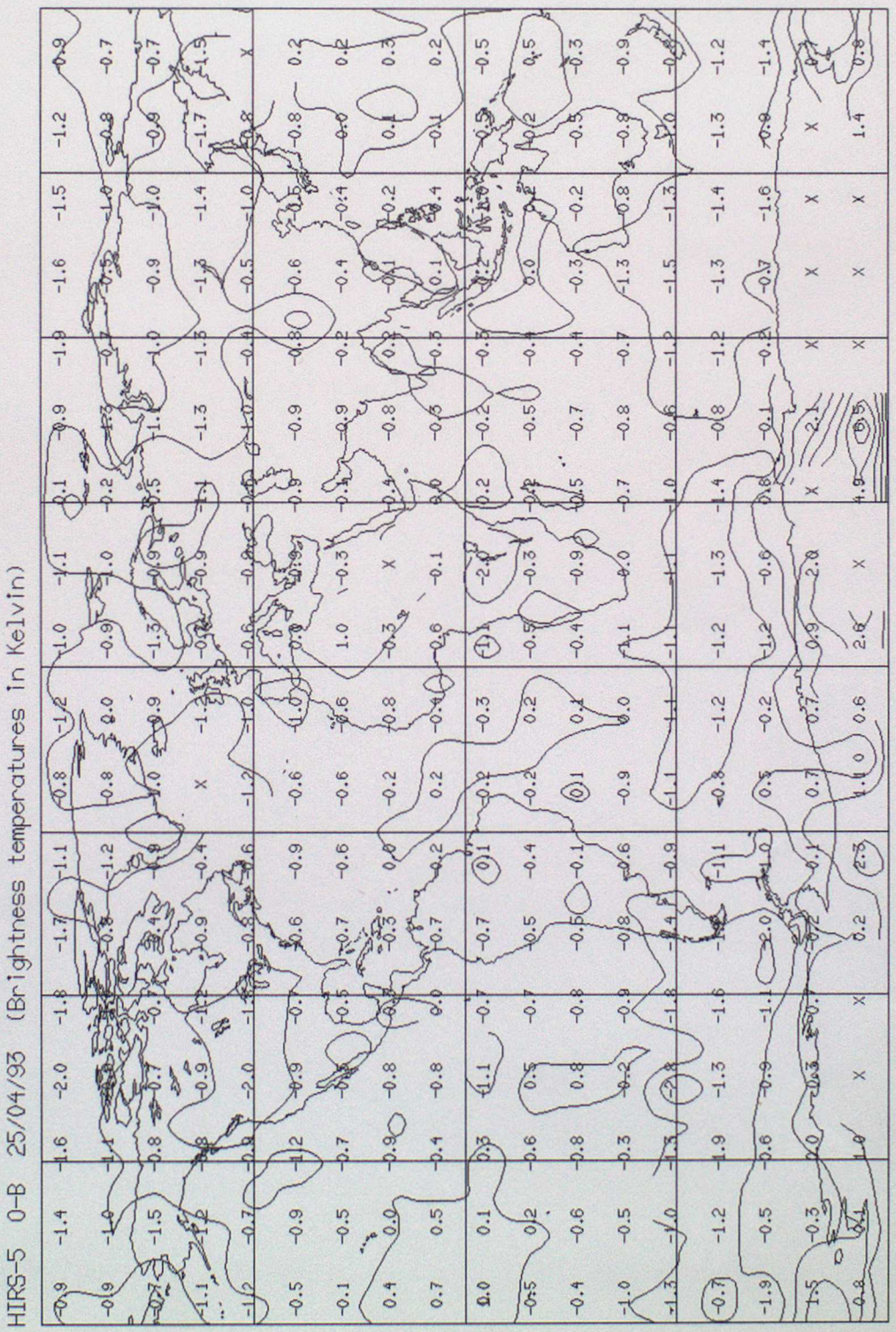
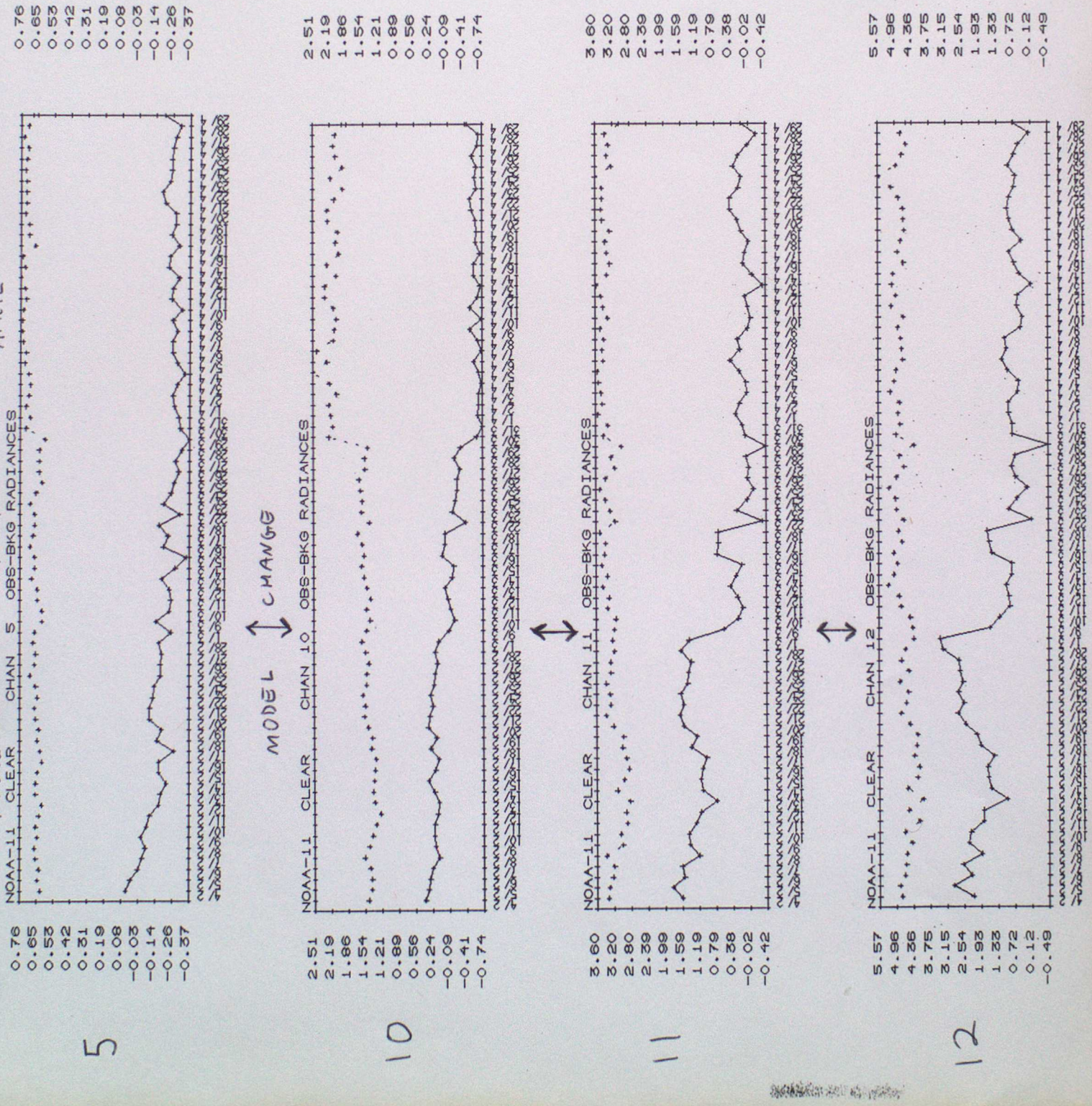


FIG. 7

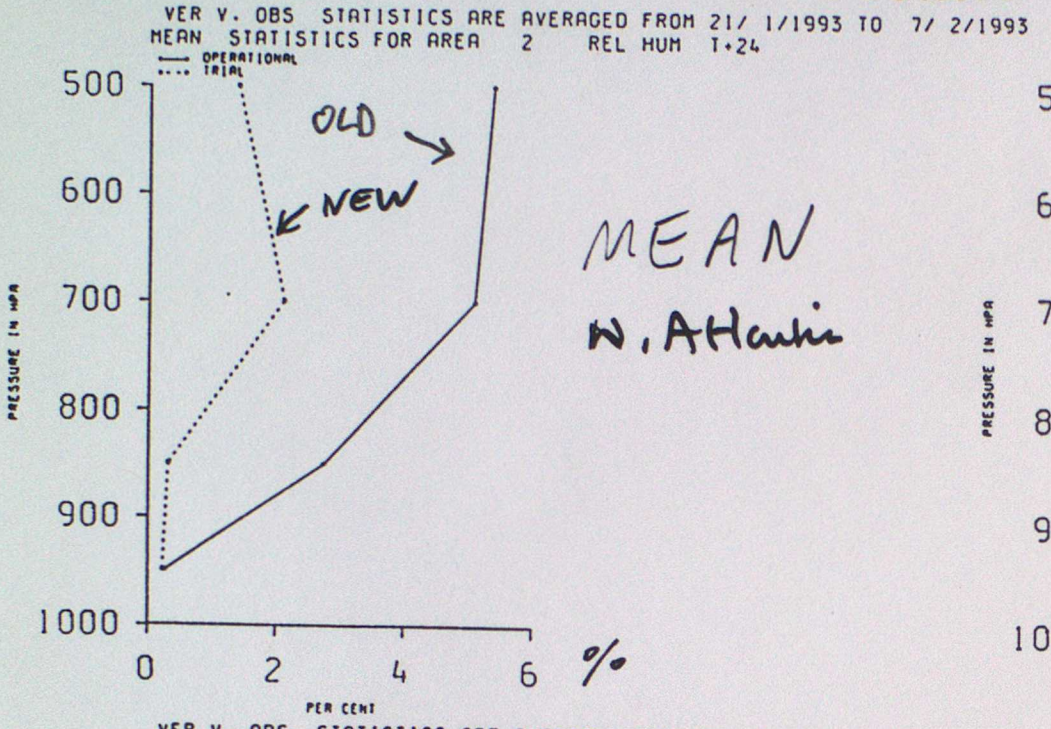
TIME SERIES: OBSERVATION - MODEL

(BRIGHTNESS TEMPS IN KELVIN)

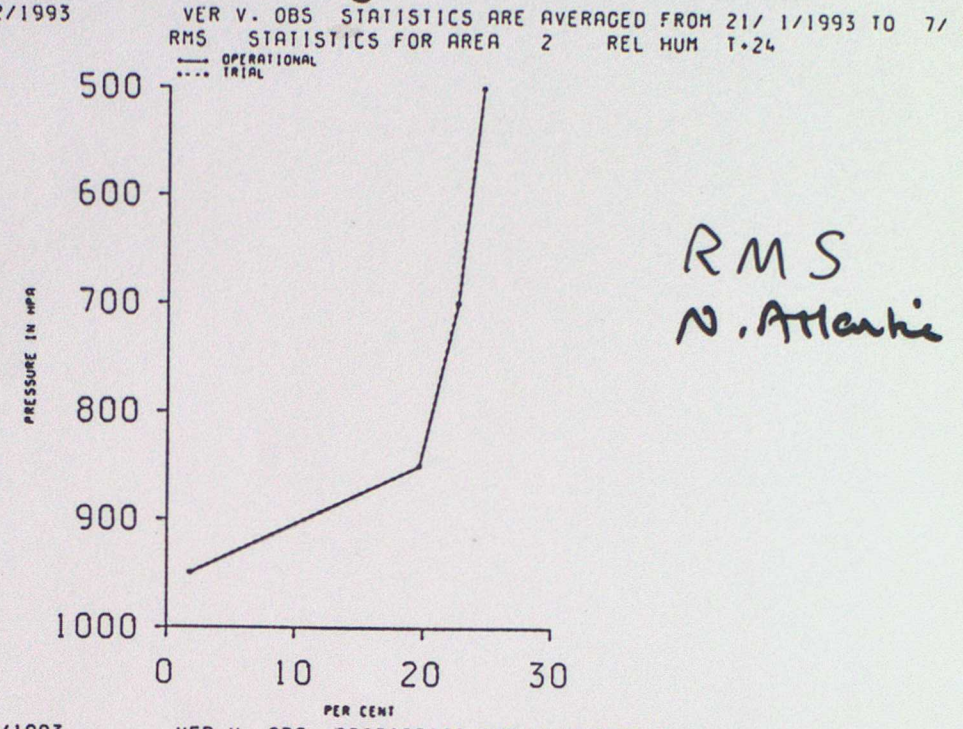
NOAA-11, GLOBAL AVERAGE



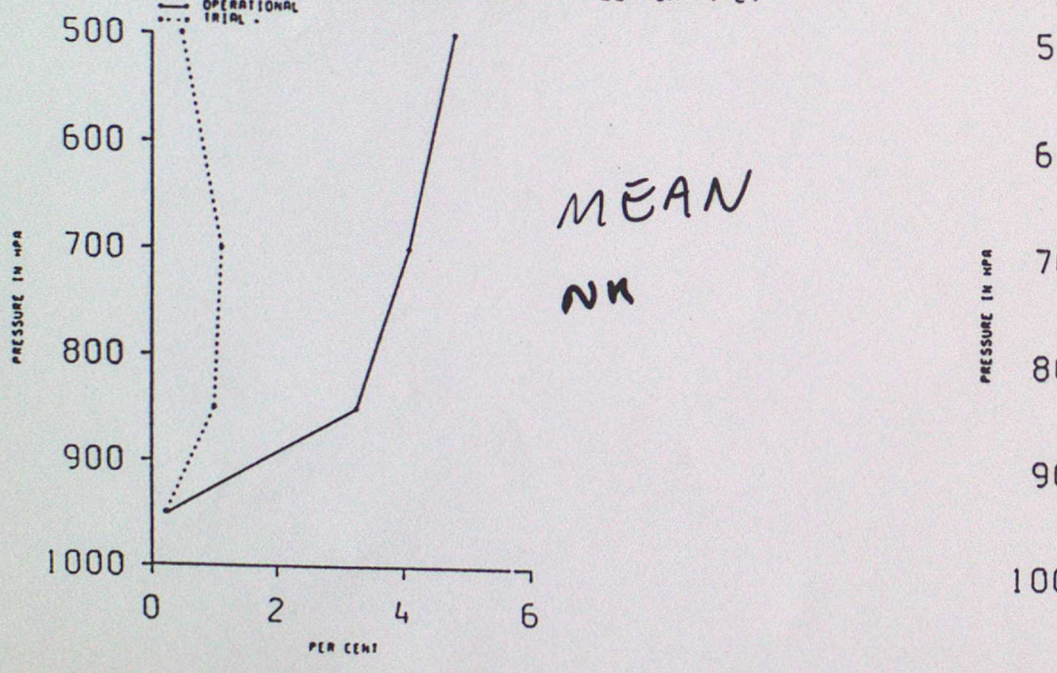
BIAS Relative Humidity T+24 RMS



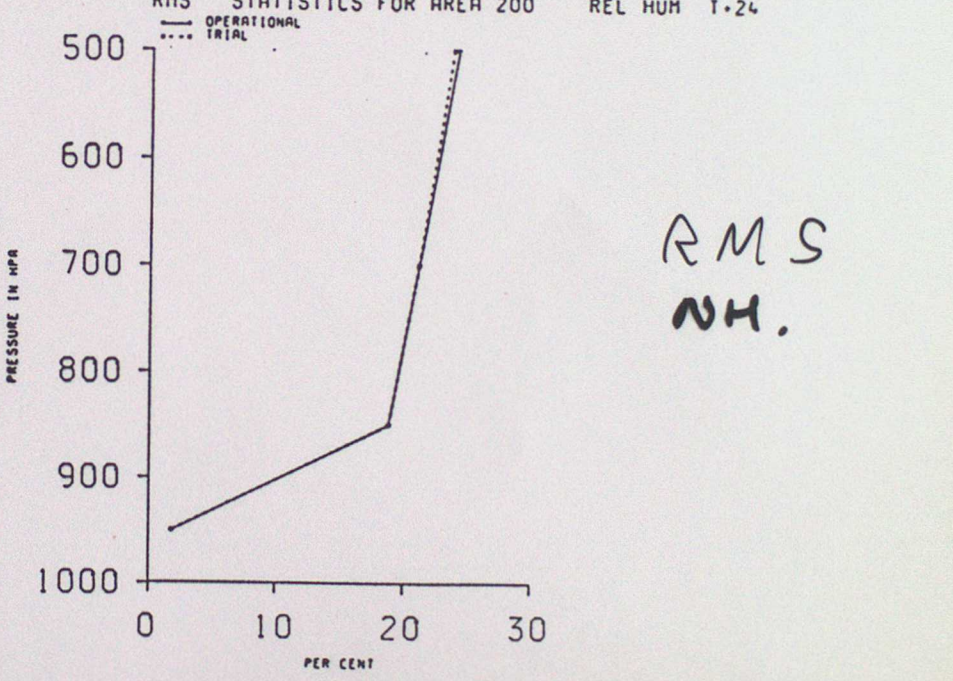
MEAN
N. Atlantic



RMS
N. Atlantic



MEAN
NH

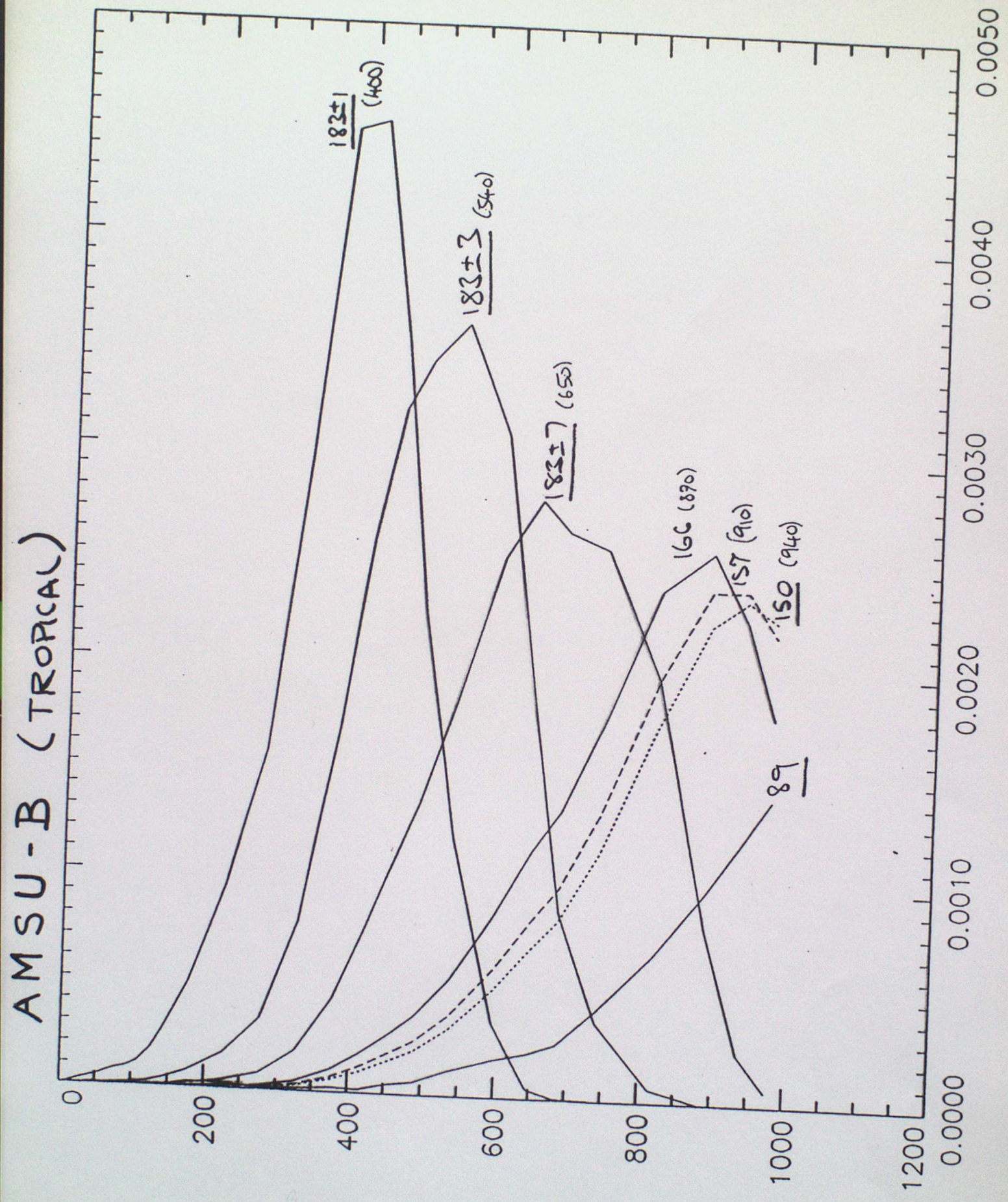


RMS
NH.

FIG. 8

VERIFICATION : MODEL – RADIOSONDE , C. WILSON (pers. comm.)

FIGURE 9

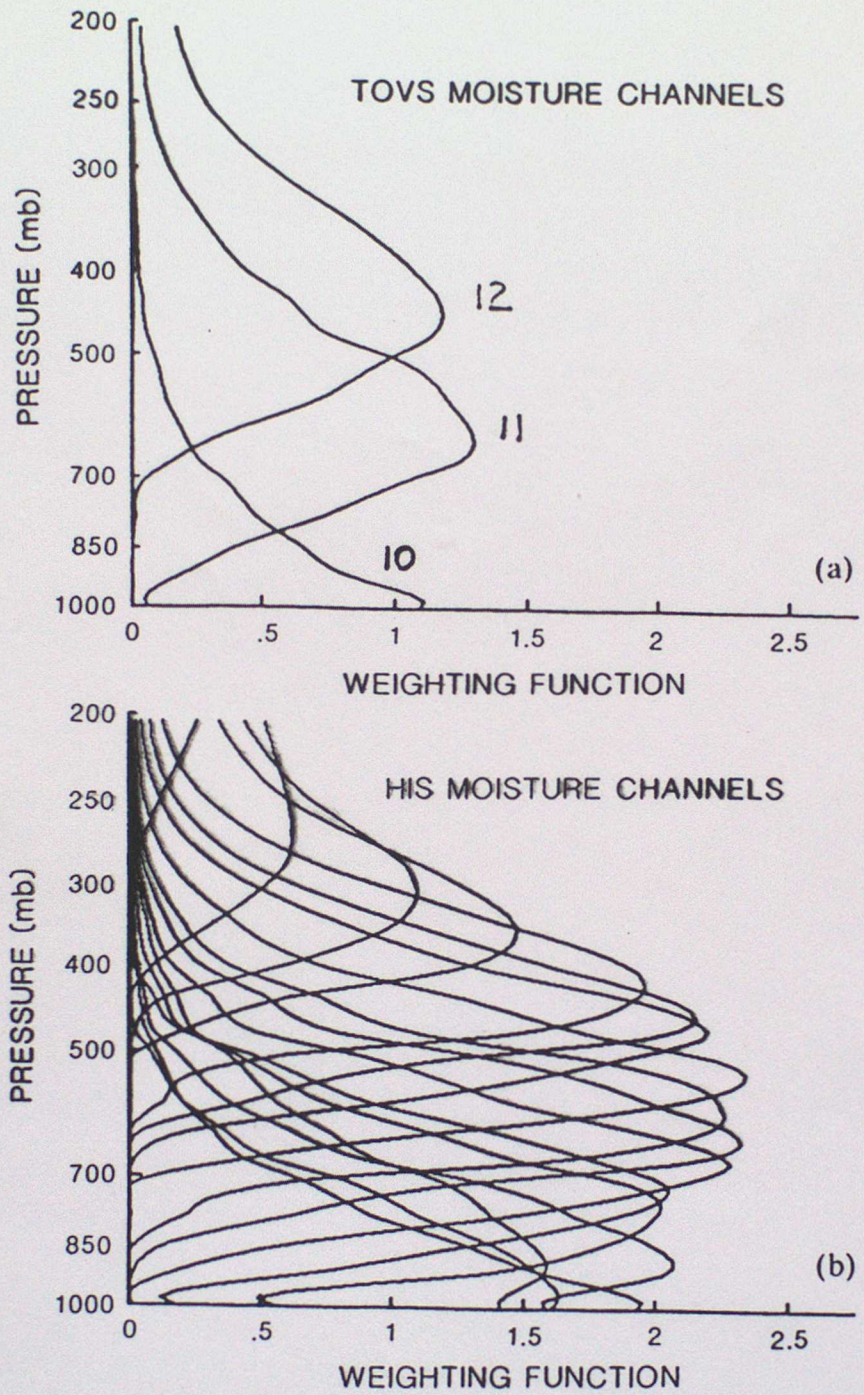


ATOVS/AMSU-B WEIGHTING FUNCTIONS

: WATER VAPOUR CHANNELS

FIGURE 10.

W. L. SMITH



Forecasting Research Division Technical Reports

Forecasting Research Division Technical Reports

1.	ON THE TIME SAVING THAT CAN BE ACHIEVED BY THE USE OF AN OPTIMISED COURSE IN AN AREA OF VARIABLE FLOW	R.W. Lunnon A.D. Marklow September 1991
2.	Treatment of bias in satellite sea surface temperature observations	R.S.Bell August 1991
3.	FINITE DIFFERENCE METHODS	M.J.P. Cullen August 1991
4.	Representation and recognition of convective cells using an object-orientated approach	W.H. Hand 30th September 1991
5.	Sea-ice data for the operational global model.	C.P.Jones November 1991.
6.	Tuning and Performance of the Atmospheric Quality Control.	N.B. Ingleby. December 1991.
7.	More satellite sounding data - can we make good use of it?	R.S.Bell January 1992.
8.	WAM/UKMO Wind Wave model Intercomparison Summary Report	Heinz Gunther ECMWF Martin Holt UK Met Office January 1992
9.	Spin up problems of the UKMO Mesoscale Model and moisture nudging experiments	Akihide Segami JMA February 1992
10.	A comparison of 2nd generation and 3rd generation wave model physics	M.W. Holt B.J. Hall February 1992
11.	RETRIEVAL AND ASSIMILATION: SYSTEM CONSIDERATIONS	Andrew C Lorenc March 1992
12.	Detection of Precipitation by Radars in the UK Weather Radar Network	M. Kitchen P.M. Brown April 1992
13.	THE VALUE OF WIND OBSERVATIONS FOR WEATHER FORECASTING AND CLIMATE STUDIES	Andrew C Lorenc April 1992
14.	An investigation into the parameters used in the analysis scheme of the Mesoscale Model	G. Veitch B.J. Wright S.P Ballard May 1992
15.	THE VERIFICATION OF MESOSCALE MODEL FORECASTS OF LIQUID WATER CONTENT USING HELICOPTER REPORTS OVER THE NORTH SEA DURING WINTER 1991	M. Ahmed R.W Lunnon R.J. Graham May 1992

Forecasting Research Division Technical Reports

16.	Simulations of the Diurnal Evolution of Marine Stratocumulus Part I: The sensitivity of the Single Column Version of the Mesoscale Model to Changes in the . Turbulence Scheme. NOT YET AVAILABLE	S.D.Jackson S.P. Ballard
17.	Simulations of the Diurnal Evolution of Marine Stratocumulus Part II: A Comparison of Radiation Schemes Using the Single Column Version of the Mesoscale Model. (NOT YET AVAILABLE)	S.D.Jackson S.P. Ballard
18.	Quantifying the low level windshear aviation hazard for the UK: some research proposals	R.J. Graham R.W. Lunnon May 1992
19.	WAM/UKMO Wind Wave model Intercomparison Part 2 Running the UKMO wave model at higher resolution	M.W. Holt April 1992
20.	Sensitivity of Mesoscale Model forecasts of anticyclonic Statocumulus to the specifications of initial conditions and Boundary Layer mixing scheme. (NOT YET AVAILABLE)	B.J. Wright S.P. Ballard
21.	Evaluation of diffusion and gravity wave changes in the Global Forecast Model.	F. Rawlins O. Hammon 16 June 1992
22.	Background Errors for the Quality Control and Assimilation of Atmospheric Observations in the Unified Model - the situation in July 1992.	C.A. Parrett July 1992
23.	Estimation of the Mean and Standard Deviation of the Random Component of Data also Containing Non- random Errors.	B.R. Barwell July 1992
24.	Experiments in Nowcasting convective rain using an object- oriented approach.	W.H. Hand 15th August 1992
25.	Gravity Wave Speeds from the Eigenmodes of the Unified Model.	I. Roulstone 28 July 1992
26.	A re-calibration of the Wave Model	M.W. Holt August 1992
27.	Evaluation of Koistinen's method of radar range and bright band correction	A.G. Davies August 1992
28.	A Study of the Boundary Layer in the Mesoscale Unified Model	Graham Veitch August 21,1992
29.	Profiles of wind using time-sequences of absorption channel imagery from geostationary satellites: proof of concept using synthetic radiances	R.W.Lunnon September 1992
30.	AN EMPIRICAL INVESTIGATION OF THE "WATER VAPOUR TEMPERATURE LAPSE-RATE FEEDBACK" TO THE GREENHOUSE EFFECT	K.F.A. Smith R.J. Allam J.S.Foot September 1992

Forecasting Research Division Technical Reports

31.	Observation needs for operational ocean modelling	S.J. Foreman September 1992
32.	Bright band correlations for layered precipitation; the comparison of Chilbolton radar data and Hardaker model output.	A.G. Davies November 1992
33.	Progress and performance of the operational mesoscale model	S.P. Ballard
34.	Assessment of the bias of significant wave height in the Met.Office global wave model	S.J. Foreman M.W. Holt S. Kelsall
35.	STUDY OF CIRRUS CLOUD WINDS: ANALYSIS OF I.C.E DATA FINAL REPORT FOR EUMETSAT CONTRACT ITT 91/16	R.W. Lunnon D.A. Lowe J.A. Barnes I. Dharssi December 1992
36.	Revisions to the operational data assimilation-Nov.92	R.S. Bell January 1993
37.	A comparison of wind observations from a flight of the DRA(B)BAC 1-11 research aircraft over Hemsby, 11 June 1991, with observations from the Hemsby radiosonde	R.J. Graham January 1993
38.	The Moisture Observation Pre-processing System	B.J. Wright January 1993
39.	Performance of the data assimilation scheme in the operational trial of the new mesoscale model.	B. Macpherson B.J. Wright A.J. Maycock January 1993
40.	DEVELOPMENT AND PERFORMANCE OF THE NEW MESOSCALE MODEL.	S.P. Ballard R. Robinson R T H Barnes S Jackson and S Woltering
41.	A PRELIMINARY ASSESSMENT OF OCEAN SURFACE FLUXES FROM UNIFIED MODEL FORECASTS	J.O.S. Alves S.J.Foreman M.W. Holt S. Kelsall S.J.Nightingale January 1993
42.	Some notes on primitive and quasi-equilibrium equations with a hybrid vertical coordinate and remarks on Hamiltonian structure.	I.Roulstone 23rd March 1993
43.	Development of the surface data assimilation scheme for the new mesoscale model	A.J. Maycock April 1993
44.	A REVIEW OF SEA ICE MODELS FOR USE IN FOAM	C.G. Sherlock April 1993

Forecasting Research Division Technical Reports

45.	Running the global wave model with shallow water depth information.	M.W. Holt April 1993
46.	An atlas of fetch-limited wave height over the North Sea	M.W. Holt May 1993
47.	VERIFICATION OF NWP MODEL WIND AND TEMPERATURE FORECASTS USING ASDAR REPORTS.	D.A. Forrester J. Human May 1993
48.	Use of Satellite data in the Operational Sea Surface Temperature Scheme.	C P Jones May 1993
49.	PARAMETRIZATION OF OPEN-OCEAN DEEP CONVECTION PART 1: THEORETICAL DESCRIPTION OF A PLUME ENSEMBLE MODEL	J.O.S ALVES MAY 1993
50.	PARAMETRIZATION OF OPEN-OCEAN DEEP CONVECTION PART 2:	J.O.S ALVES MAY 1993
51.	A CASE STUDY OF THE IMPACT OF RADIOSONDE TEMPERATURE AND WIND PROFILES ON MODEL FORECASTS OF A DEVELOPING ATLANTIC DEPRESSION	R.J. GRAHAM MAY 1993
52.	Balanced Surface Pressure and Temperature Increments derived from Wind Increments in the AC Assimilation Scheme.	P.L. Andrews R.S. Bell June 1993
53.	A method of improving the analysis of cloud top height for the New Mesoscale Model.	W.Hand 30th June 1993
54.	Operational changes affecting the quality control of atmospheric data used by the Unified Model during 1992	Colin Parrett June 1993
55.	Modelling the wave energy spectrum in shallow water	M W Holt July 1993
56.	OPERATIONAL PERFORMANCE OF MESOSCALE AND LAM MODELS IN PREDICTION OF STRATOCUMULUS	S.P.Ballard B.Macpherson 31st August 1993
57.	Project definition study of icing atmosphere for aircraft design	R W Lunnon July 1993
58.	Evaluation of Nimrod radar corrections- Report to the Nimrod project board.	M Kitchen R Brown A G Davies August 1993
59.	Rainfall on the 22nd September 1992	M J Bader
60.	A COMPARISON OF INERTIAL STABILITY CONDITIONS IN THE PLANETARY SEMI- GEOSTROPHICAND QUASI- EQUILIBRIUM MODELS	G.VEITCH AND M H MAWSON
61.	VALIDATION OF MODEL WATER VAPOUR USING TOVS SATELLITE	R. RENSHAW SEPT.1993

Forecasting Research Division Technical Reports

62. Automatic application of orographic corrections

Davis A.G.
September 1993